Journal of Trends in Computer Science and Smart Technology (ISSN: 2582-4104)
www.irojournals.com/tcsst/

Secure and User-Friendly Smart Home Automation: A Mobile-Centric IoT Approach

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Abstract

Home automation systems (HAS), leveraging the power of the Internet of Things (IoT), are gaining significant attention for their potential to reduce costs, labor, and human error. As the demand for smart home technologies grows, effective energy management and cost reduction become increasingly important. This research explores the technical landscape of IoT-based HAS, focusing on remote control and management of home appliances through smartphones and dedicated applications. A comparative analysis of various HAS solutions will be conducted to evaluate their functionality, usability, and energy efficiency. Additionally, the study will examine the security and privacy implications of IoT-based home automation and potential barriers to adoption such as cost and complexity. By addressing these key issues, this research aims to contribute to the development of more effective and accessible smart home solutions.

Keywords: Automation, IoT, Intelligence, smart home systems, Zigbee, Raspberry Pi, Arduino.

DOI: https://doi.org/10.36548/jtcsst.2024.2.007
Received: 17.04.2024, received in revised form: 09.05.2024, accepted: 23.05.2024, published: 06.06.2024

1. Introduction

The escalating demand for the Internet of Things (IoT), driven by the ever-growing need for internet connectivity [1, 2], has spurred the development of remotely accessible interconnected devices [3, 4]. This study focuses on the transformative potential of IoT within smart homes [5], specifically examining the management and control of household devices using wireless mobile technologies. Central to this research is developing and implementing a unique microchip, acting as an internet gateway that enables automated and user-controlled functions [6-9]. We aim to address key challenges such as seamless device integration, intuitive user interface design, robust data security, and the overall impact of IoT on daily living. This paper delves into the evolving landscape of IoT-based home automation systems (HAS), examining their potential to revolutionize how we interact with and manage our living spaces. Through a comprehensive literature review and comparative analysis of various HAS solutions, we will explore the functionalities, usability, and energy efficiency of these systems. We will also address critical challenges such as data security, privacy concerns, interoperability issues, and barriers to adoption like cost and complexity. By investigating these facets, this research aims to contribute to the development of more effective, secure, user-friendly, and accessible smart home solutions. Ultimately, this paper seeks to provide a comprehensive overview of the current state of IoT-based home automation and its potential for shaping the future of smart homes.

2. Literature Review

In this section, we have reviewed various research papers on IoT-based Home Automation systems on different models and summarized our views below.

Gomathy, C K. (2022). In this article [19] the author discusses the implementation of home automation using IoT that encompasses various technologies like Bluetooth, Zigbee, and cloud-based systems, each enhancing the convenience, energy efficiency, and security of smart homes. Bluetooth-based systems enable smartphone control of appliances via Arduino BT boards, while Zigbee modules offer reliable, low-power communication. Cloud-based systems facilitate remote monitoring and control, leveraging cloud services for data storage and advanced features. Emphasis is placed on security, with methods like NFC ensuring privacy. The global IoT market is rapidly growing, driven by increasing smart home adoption, with significant benefits including automation of routine tasks, energy savings, and enhanced

security. Future IoT, AI, and machine learning advancements promise even more intuitive, efficient, and secure home automation systems.

Alani et al. (2021) the author has introduced a full architecture and execution of a progressive, cost-effective networked embedded system in this paper [20]. The devices can function efficiently even at remote locations thanks to IoT technology. The purpose of this study is to assess the applicability and cost of the NetPi and BLYNK network systems. While contrasting many criteria might be met by employing numerous modules under the control of the primary supervisor, as per NeTPi. However, when more than one microphone controller was utilized, BLYNK displayed guidelines about the project's layout in a single GUI. On one hand, the cost is regarded as expensive due to BLYNK's energy-based constraints, which limit customers' ability to meet their layout demands; on the other hand, the BLYNK performance is user-friendly.

Kadiyan et al (2023). This paper [21] explores the design and implementation of a smart home automation system using IoT technology, focusing on remote control, energy efficiency, security, and convenience in residential settings. It discusses the components involved, such as sensors, actuators, and a central control hub, enabling automation and monitoring of home devices. The future potential of smart homes is highlighted, with advancements in IoT, artificial intelligence, and connectivity leading to more intelligent and personalized home environments. Additionally, the paper emphasizes the importance of addressing privacy and security concerns, ensuring user data protection and trust in these systems. It also mentions the significance of interoperability with devices, integration with smart grids, and smart cities for a more connected and sustainable living environment. Various studies and research on the benefits and implementation of IoT-based home automation systems are also discussed.

B.N et al(2023). The document [23] "Smart Home Automation Using IoT" discusses the implementation and benefits of smart home systems leveraging the Internet of Things (IoT). It highlights how IoT enables the remote monitoring and control of home appliances such as lights, fans, doors, refrigerators, and washing machines, enhancing convenience, security, and energy efficiency. The system primarily uses microcontrollers like Arduino UNO connected to the internet through USB serial or ESP8266 WiFi modules, which allow users to manage their homes from anywhere. The paper also outlines various wireless communication methods for

home automation, including Bluetooth, Zigbee, GSM, and Wi-Fi, emphasizing the integration of these technologies to create a seamless and user-friendly experience. The study illustrates the advantages of smart homes, such as improved safety, comfort, and economic benefits, while also detailing the design and development requirements for such systems, including system management, data analysis, and security specifications.

Stolojescu-Crisan et al(2021). The researcher of this report [24] developed a scheme for tying sensors, controllers, and other information originators together to enhance house flexibility. The app is entitled as a toggle and is a program that uses an Application Programming Interface or (API) to accomplish its goals. It serves as the foundation for a simple and uniform data transmission system. Sensors and actuators were among the devices employed with toggle, which helped to improve network connectivity in the API interface. The majority of toggle devices, as per the author, are centered on ICs like ESP8266/ESP8285 or Raspberry platforms. A mobile app that gives consumers the power to manipulate a range of quality apps and detectors was designed. This arrangement of toggles was simple to use, adaptable, and it could also be customized.

3. IoT and Home Automation

IoT- IoT represents a large area where different electronic devices operate automatically. These electrical devices may be connected to sensors and the web. They are designed to regulate and manage various devices or electronics remotely. Many advanced applications of IoT machines are made to make consumer life easier.

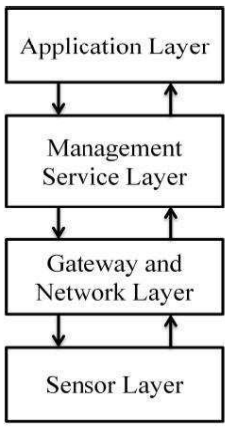

Figure 1. The Architecture of IoT [36]

Home Automation- Automation is a system that directs the method of the most recent and most advanced technology with human effort. There has been a dramatic increase in researchers' efforts to satisfy this dream. Automation is employed not only at the economic level but also at the house level tools as a result, simple autonomous homes have advanced. Bluetooth, GSM, Wi-Fi, and other software platforms are all available. Different devices such as Node MCU ZigBee, Raspberry Pi, and Arduino are accessible at the connection level. Connecting numerous home-sensing devices to a PC is a standard function. At the server level, the PC gets data from sensors and changes the online page accordingly. The user can use the PC or be able to log in and check the status of their homes. This can be very useful for older residents to take care of their houses. Home automation provides security, privacy, and comfort to the user.

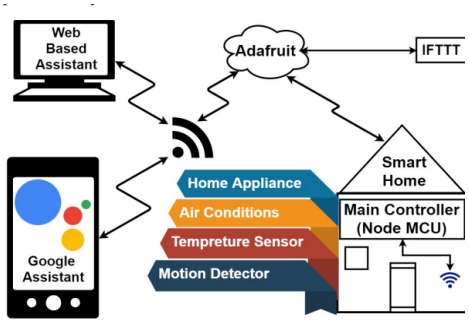

Figure 2. Smart Home Automation System [37]

A. Advantages of IoT with Home Automation

- IoT devices don't require user intervention. Transferring data to the device allows the user to track and monitor processes. Such equipment is employed in a locality where there are similar requirements.
- IoT devices can save the user valuable time. Using such devices prevents the user from performing identical tasks multiple times. Transferring device to device allows the user to induce better performance. Therefore, direct results are widely available.
- Efficient use of power and resources may be achieved through IoT, it’s possible to adopt this technology at cheap prices. Also, the devices should be under strict observation.

- All AI-based applications work well to make our daily lives better. Such devices work to enhance our comfort and provide better management. So it's obvious that our standard of living will improve.
- The set system can monitor the opening and shutting of windows, and shades in terms of solar space and airflow to regulate the temperature, and humidity and regulate fresh air inside the house. Due to this system, we can monitor emissions from factories and cars to reduce pollution.
- IoT-based devices are also helpful in identifying health-related issues. Such devices add hospitals to produce medical aid. Also, such resources are helpful for the elderly and therefore the disabled.

B. Application of Home Automation System

1. IoT-based HAS with Real-Time Monitoring

Bhattacharyya et al. [10] suggested a real-time communication model for an IoT-based smart grid system using a microcontroller, local area network connection, text-supported mobile phones, GSM SIM300, and SC 547 bipolar junction to manage diverse uses such as illumination and DVD player control in 2020. The astronomic clock and ground clock are used to maintain task deadlines in real-time pre-based programming, SMS, or multi-user tasks. The short-term real-time time deadline (SDFRTTS) method has been used for shortening SMS. In this program, each user may upload only one job at a time, and a distinct engine handles each task.

2. Saving the Power of the Home Automatic System Utilizing Various Detectors

Lohan along with Singh [11] presented an autonomous system in 2019 to preserve energy by using different types of instruments such as motion detectors, light sensors, humidity sensors, and so on. Motion and light detectors are used in the kitchen and washroom. When the motion detector indicates a presence (with a value of 1), the room light is adjusted based on the light source. Lights are required when the light threshold (Li-) is exceeded. The air conditioner is turned off if the temperature rises above 25 degrees Celsius. The system employs seven motion sensors, eight light sensors, and four thermocouples. A data analysis of power consumption revealed that 79.59% of light and 20% of AC power was conserved, with a total of 20% savings set aside for a month [12]. Each function has two parameters: (1) an OPEN/OFF

signal, with OPEN represented by one and OFF by zero, and (2) various binary bits denoting activity constraints.

C. Challenges in Implementing IoT-based Home Automation

Implementing IoT-based home automation systems presents several challenges, but proactive solutions can address these hurdles and pave the way for widespread adoption:

Data Security and Privacy

- Challenge: IoT devices collect sensitive personal data, making them vulnerable to cyberattacks and privacy breaches.
- Solution: Prioritize robust security measures such as encryption, strong passwords, two-factor authentication, and regular software updates. Utilize firewalls and intrusion detection systems. Educate users on security best practices and the importance of safeguarding their data.

Interoperability and Standardization

- Challenge: Lack of standardized communication protocols between devices from different manufacturers hinders seamless integration.
- Solution: Encourage the adoption of universal standards like Matter (previously Project CHIP) to ensure compatibility across different brands and devices. Develop open-source platforms and APIs that facilitate easy integration and communication between devices.

Complexity and User Experience

- Challenge: Setting up and managing multiple IoT devices can be complex and overwhelming for non-technical users.
- Solution: Design intuitive user interfaces, provide comprehensive user manuals, and offer accessible customer support and troubleshooting resources. Simplify the initial setup process and prioritize user-friendly features for a seamless user experience.

Cost

- Challenge: The initial investment in IoT devices and systems can be high, deterring some consumers.
- Solution: As technology advances, the cost of IoT devices is expected to decrease. Offer tiered pricing options or bundled packages to cater to different budgets. Highlight the long-term cost savings potential of IoT automation, such as reduced energy bills and improved efficiency.

Reliability and Maintenance

- Challenge: IoT systems can experience technical glitches, and connectivity issues, and require ongoing maintenance.
- Solution: Choose reputable brands with reliable products and invest in a stable network infrastructure. Provide user-friendly troubleshooting guides and remote support options to address technical issues promptly.

Scalability

- Challenge: As the number of connected devices increases, the system's performance may deteriorate and become difficult to manage.
- Solution: Design systems with scalability in mind. Choose protocols that can efficiently handle many devices. Utilize cloud-based data storage and processing solutions to offload some of the computational burden from local devices.

By proactively addressing these challenges, the full potential of IoT-based home automation can be realized, leading to more efficient, secure, convenient, and accessible smart homes for everyone.

4. Home Automation Systems Technologies

A. Home Automation using Raspberry Pi

This type of program is created with the latest version of Android [13]. An interface badge must be established to connect with the Windows program. Such a module is necessary for single-user encoding/decoding, using workstations, home appliances, and Raspberry Pi with embedded sensors. The program includes the required capabilities to operate the shutter with the Raspberry Pi card, including a smartphone, database server, and Raspberry Pi. Instead of following a relatively simple construction, an autonomous residence can be built without the latest wiring and with or without interface with other structures [14]. By using the mentioned app, the Android app and Raspberry Pi integrate with HAS, allowing it to run different apps in various ways. The user can trade various Raspberry Pi plans by creating a connection with a wireless modem. The primary objective of HAS is to connect a handset to the home network using this Raspberry microcomputer.

B. Home Automation using Arduino

As the information in the machine starts to process, the model shown in Figure 3 [38] makes the Arduino model functional. The system investigates the components and connections of a large unit [15]. An error notification is issued whenever any form of error is identified. If no errors are identified, the model will consider the situation correct and connect to the nearest Wi-Fi network. The system will then re-evaluate whether the main unit's ESP8266-01 is connected to the network. If no connection is available, the system will redirect to the error site. The Arduino Uno is implemented as a key planning system for managing electrical appliances and a Wi-Fi device in this system. Figure 3 [38] depicts the base model for the proposed system.

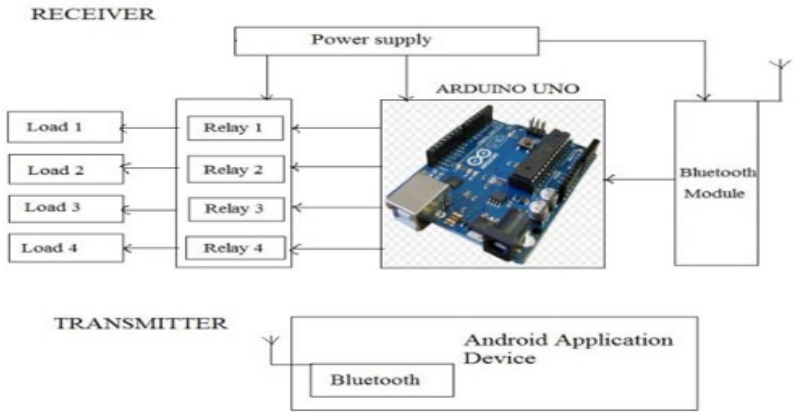

Figure 3. Use of Arduino in Home Automation [38]

C. Home Automation Using Zigbee

Wireless mesh network technology evolved into an open worldwide standard to meet the long-awaited demand for low-cost, low-power wireless IoT networks. The IEEE 802.15.4 physical radio frequency is used in unlicensed bands such as 2.4 GHz, 900 MHz, and 868 MHz through the ZigBee standard. This type of device, utilizing a wireless sensor network (WSN), is primarily used to monitor environmental dangers to humans and wild animals. It tracks physical or natural variables such as temperature, pressure, and humidity [16]. For the establishment of wireless networks, enhanced communication protocols such as ZigBee [17] are deployed to sustain the mesh network's topology and transmit more data over longer distances. It transmits data across distances of 10–100 meters [18], depending on the context.

5. Comparative Study

The following Table 1 gives a comparison between the different HAS with respect to their speed, cost, and availability. The advancements in HAS recorded in the last decade are presented in Table 2.

Table 1. Comparison of Different HAS Models

System	Cost	Speed	Availability
GSM using microcontroller	High	Slow	High
Voice Recognition using Kinect Sensor	Low	Fast	Low
Bluetooth using Arduino	Low	Fast	Low
IoT	Low	Fast	High

Table 2. Advancements in Home Automation Recorded in the Last Decade

[25]	PIC	Mobile App	Control Indoor Appliances
[26]	Arduino	Application on smartphone	Within a small range, manage interior and exterior appliances
[27]	PIC	Application on smartphone	Manage interior and exterior appliances
[28]	Arduino MEGA	Application on smartphone	Manage interior
[29]	ARM processor	settings	indoor automation solution
[30]	Raspberry PI, NodeMCU		humidity, light, movement, and power are all regulated.
[31]	Laptop/PC server	Application on smartphone	Interior device control, although not yet deployed
[32]	Linux board	Graphic User Interface	control HVAC appliances
[33]	Raspberry PI	Available on the internet and smartphone	Appliances may be controlled remotely
[34]	TI-CC3200 MCU	Application on smartphone	monitor moisture levels of ground and indoor appliances

[35]	Raspberry PI	Application on smartphone	control indoor appliances

Table 3. Different Types of Controllers and the Protocols used for IoT

Controller Type	Protocols Used	Performance Characteristics	Suitable Scenarios
Microcontrollers	Wi-Fi, Bluetooth, Zigbee, Z-Wave	Cost-effective, low power consumption, flexibility	DIY projects, small to medium-sized homes, a limited number of devices
Single-board Computers	Wi-Fi, Bluetooth, Ethernet	Powerful processing, expandable, supports complex automation	Larger homes, extensive device networks, advanced features, local processing, custom applications
Cloud-based Hubs	Wi-Fi, Zigbee, Z-Wave	Easy setup, remote access, wide device compatibility	Users prioritize convenience, remote management, and integration with a wide range of devices and services
Smart Speakers/Voice Assistants	Wi-Fi	Convenient voice control, limited device compatibility	Simple automation, hands-free operation, users who prefer voice commands
Dedicated Gateways	Varies (Wi-Fi, Zigbee, Z-Wave, etc.)	Protocol-specific, optimized for specific device types	Homes with numerous devices using a particular protocol need centralized control and automation

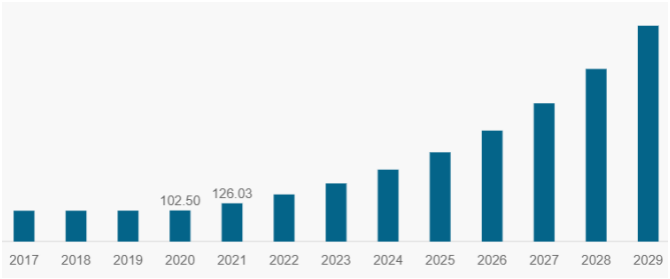

Figure 4. North America Internet of Things Market Size, 2018-2029 (USD Billion) [39]

As per the graph and the latest trends in the market, by 2029 the market size of IoT in North America is predicted to be around USD 2,465.26 billion, which is around 5 times the current size of the market. The market is projected to grow at a CAGR of 26.4% during the forecast period, with Asia Pacific to be the highest CAGR. Smart city initiatives will be the key factors in driving the market towards growth.

6. Methodology

To ensure a comprehensive and up-to-date understanding of the current state of IoT-based home automation, a systematic approach was adopted for reviewing relevant literature. This approach involved:

1. **Database Searches:** Extensive searches were conducted in prominent academic databases such as IEEE Xplore, ACM Digital Library, ScienceDirect, and SpringerLink. These databases contain a vast repository of peer-reviewed articles, conference papers, and technical reports.

2. **Keyword Refinement:** Specific keywords and phrases were employed to refine the search results. These included terms like "Internet of Things," "smart home automation," "home appliances," "remote control," "mobile applications," "energy efficiency," "security," "privacy," "challenges," and "solutions."

3. **Inclusion and Exclusion Criteria:** Strict criteria were established to determine the relevance and inclusion of papers in the review. Only peer-reviewed articles and conference papers published within the last five years were considered, ensuring that the most recent and relevant research was included.

4. **Snowballing Technique:** References cited in the initially selected papers were examined to identify additional relevant sources. This snowballing technique helped expand the scope of the literature review and uncover potentially overlooked publications.

5. **Critical Appraisal:** Each selected paper was critically appraised to assess its methodological rigor, theoretical soundness, and contribution to the field of IoT-based

home automation. This involved evaluating the research design, data collection and analysis methods, and the validity of the conclusions drawn.

7. Conclusion

We began by discussing the interpretation of the word Internet-of-things, and its expansion and architecture over the past decade. Along with the advancements in the field of HAS, its advantages, and applications as presented by various researchers in their papers. The next topic we took on was the use of various technological work involving Home Automation systems like Raspberry Pi, Arduino board, ZigBee software, etc. Then we compared various works done by prestigious researchers in this field under the literature review section. Later, we conducted a comparative study based on several variables such as the system's credibility, affordability, and comparison of many distinct smart home devices produced in the last decade. Lastly, a graph predicting the growth of IoT as a sector in the coming decade is presented. In future, more work can be done to make the current system more efficient and affordable.

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Author's biography

Rishi Matura - An Undergraduate student currently studying at Chandigarh University, pursuing a B.E. in Computer Science and Engineering (CSE), and currently in the program's final year. Passionate about technology, with a particular interest in software development for the Android Operating System and Neural Networks. Thrives on collaborating with others to deconstruct complex challenges and devise creative, effective solutions. Proactive in anticipating and mitigating potential problems.

Kunal - Kunal, a final-year Computer Science and Engineering student at Chandigarh University, is passionate about applying his knowledge to real-world challenges. He is actively seeking opportunities in research and development. With a strong academic foundation and eagerness to learn, he is a dedicated and motivated individual ready to embark on his professional journey.